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PETROGRAPHIC FEATURES AND MODELLING OF SOME WATERFALL ROCKS IN KENYIR LAKE, TERENGGANU: A MICROSCOPIC PERSPECTIVE APPROACH IN SUSTAINABLE GEOTOURISM

MUHD NUR ISMAIL ABDUL RAHMAN[1]*, AHMAD NORZAIMIE ROSLAN[1], SITI SYAZA AIMAN SHE WALI[1], NOR BAKHIAH BAHARIM[2], AZMAN ABDUL GHANI[3] AND CHE AZIZ ALI[4]

[1]Paleoceanography Research Group (PoRIG), Faculty of Science and Marine Environment, University Malaysia Terengganu, 21030, Kuala Nerus, Terengganu, Malaysia. [2]Faculty of Science and Marine Environment, University Malaysia Terengganu, 21030, Kuala Nerus, Terengganu, Malaysia. [3]Geology Department, Faculty of Science, University of Malaya, 50603, Kuala Lumpur, Malaysia. [4]Geology programme, School of Environmental and Natural Resources, Faculty of Science and Technology, University Kebangsaan Malaysia, 43600, Bangi, Selangor, Malaysia.

**Corresponding author: nur.ismail@umt.edu.my*
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Abstract: Waterfalls around Kenyir Lake, Terengganu, naturally serve as an iconic symbol of amazing rock bounded formation amidst the wilderness, which stores a hidden story for millions of years. The waterfalls feeding Kenyir Lake have become tourists' main attractions since they are located separately on different islands. There are three naturally picturesque waterfalls worth sight-seeing in the study area, namely Sungai Buweh Waterfall, Lasir Waterfall and Saok Waterfall, which are made up of granitic rock bodies that emerged in the Eastern Belt during the Late Triassic. To date, the waterfall landscape displayed in any area concerning geotourism focuses more on outcrop architecture and geomorphological features but with limited accessibility to the rock records. Thus, this study is carried out to evaluate the geo-heritage features of the waterfall landscape and its rock-forming minerals. Four rock samples were carefully collected from the waterfalls and subsequently prepared for optical thin section petrography analysis using a polarised light microscope. The petrographic analysis will determine the precise mineral compositions, fabrics and microstructures under plane polarised light (PPL) and cross-polarised light (XPL) at different magnifications. In addition, petrographic modelling was constructed using integrated software *Autodesk 3ds Max* and *Debrismaker 2.0* from optical microscopic data to help identify a microscopic mineral in detail so that the mineral becomes clear to both geologists and the public at large. Generally, this modelling will enlighten the public on the material embedded in the rocks, illustrate the importance of learning about a rock-forming mineral and bring this futuristic idea with Sustainable Development Goal 15 (SDG). Besides making geology an interesting field for young geologists and the public, this mineral affirms the beautiful scenery of waterfalls for tourism, thereby connecting the interrelationship between geotourism and nature. In this regard, the current study was carried out to evaluate the geo heritage features and use an interactive learning platform for interpreting rock-forming minerals and their function towards sustainable geo-tourism.

Keywords: Kenyir Lake, granitic rock, petrography, geology, geotourism.

Introduction

Kenyir Lake, Terengganu, is situated on the east coast of Peninsular Malaysia, sharing borders with the western part of Kelantan and the southern part of Pahang. As a result of the damming of several rivers from 1978 to 1985 to create the Sultan Mahmud Hydro Electric Power Plant, the Kenyir Lake becomes the largest artificial lake in Southeast Asia (Faiz *et al*., 2010; Wan Nur Hidayah, 2014), covering an area of 260,000 hectares. The lake generally provides a dam to generate electricity and prevent flooding. Kenyir Lake is well-known for its naturally beautiful scenery, comprising amazing flora and fauna. As such, the lake is a habitat for numerous freshwater fishes and exotic wildlife species (Adam, 2019). Apart from its breathtaking beauty, the lake is also surrounded by tropical rainforests, making it one of the main tourist attractions. According to Adam (2019), Kenyir Lake serves as a great home for many species of flowers, valuable woods species, birds, insects, plants and trees, orchids, fungi and other unexplored fauna. Besides, the lake greatly serves as a tourist visiting area in Hulu Terengganu from 2008 until 2017, thereby increasing the number of tourists yearly (Central Terengganu Development Authority, KETENGAH, 2015). Hence, this indicates that Kenyir Lake has the potential to become one of the most famous tourist destinations in Malaysia and the world.

Kenyir Lake lies at a latitude of 4° 46’ N and longitude 102° 35’ E and receives water inputs from the main river, the Terengganu River Basin (Suratman *et al*., 2005) (Figure 1). The lake covers 260 km^2 with 340 small islands, limestone caves and more than 14 waterfalls, including rivers. The topography of Kenyir Lake and the surrounding area achieve a maximum elevation of about ~ 1500 meters, while its area encircles with rugged terrains, mainly at North and South and the lower area (i.e., the middle part) is completely submerged by the water. Evidently, according to Ambak & Jala (2006), Kenyir Lake is inundated by more than 10 big rivers and numerous small (feeder streams) continuously flowing into the lake. The lake also has an average depth of 37 meters with a maximum depth of 145 meters (Khairul Amri *et al*., 2020).

The lithologies of the Kenyir lake catchment area are mainly dominated by felsic-intermediate igneous rocks of granite-granodiorite andesite-basaltic andesite, marine clastic of sandstone-shale with minor occurrences of phyllite, quartzite and carbonate. Generally, the eastern part of Kenyir Lake is underlain by granitic rocks of Kapal batholith, composed of composite rock types that range from diorite to monzogranite in composition and are dominated by granodiorite. The granites in both areas are also intruded by mafic dykes to intermediate composition with an average thickness of 10 cm to 50 meters, while the petrography of granite rocks mainly contains quartz and feldspar, constituting between 90% and 35% of the total alkali feldspar (MacKenzie *et al*., 1982). Some accessory minerals such as hornblende or biotite, the most common mafic minerals in a rock and muscovite, may also be present. Based on the classification of igneous rock, granite with more than 90% of the feldspar (i.e., alkali feldspar) is known as alkali granites; the alkali feldspar between 35% and 65% of the total feldspar is known as adamellite, while the rock with quartz content between 5% and 20% will be classified as a quartz monzonite.

Geological features as a tourism attraction with a geo-heritage value have recently been accepted and promoted around the world, like in Langkawi Geopark, Malaysia, now introducing the geo-tourism classification for a potential geopark. Geo-tourism has been developed to minimise the negative impacts of mass tourism at tourist sites around geological and geomorphological attractions (Newsome & Dowling, 2010), which primarily emphasises sustainable tourism development in rural and natural environments. Accordingly, some geological-geomorphological features should include geo-heritage values such as rock outcrops, rock units, fossils, weathering processes, waterfall landscapes, minerals and tectonic structures. On the other hand, a geopark is a tool for sustainable development that also serves as a global marketing concept. As defined by UNESCO (2006), a geopark is a protected area that comprises many geological heritage sites of particular importance, rarity, or aesthetic appeal and is one of the elements in an integrated concept of protection, education and sustainable development. As such, both geo-tourism and geopark may be seen as attractive tools for rural development in many peripheral areas facing emigration.

Over the past few decades and perhaps earlier, individuals involved in the development of educational materials across various academic fields have sought to implement available novel technologies at the time (Manduca, 2007; Pringle, 2015), for instance, simulated fieldwork (e.g., Houghton *et al*., 2015), e-gaming (e.g., Pringle, 2014) and virtual reality (e.g., Domingo & Bradley, 2018; Rogers, 2020). This also includes the use of optical petrography, where educators supplemented their teaching with additional resources such as manuals of microscope images (photomicrographs) (e.g., Choh & Milliken, 2004), digital tutorials (e.g., Milliken *et al*., 2003), computer programmes and packages such as the Open University's Virtual Microscope Project (2012), analogue experiments (e.g. Brady, 2009), integration of published research materials (e.g., research-led teaching; Peck, 2004) and fundamental changes to course design and structure (e.g., Perkins, 2005). Therefore, in the current study, an interactive learning method will be proposed to educate the public about rock-forming minerals and discussed in the following section in detail.

Since geo-tourism has become a popular topic in many sustainable development areas, mainly in the tourism sector, a potential geopark is likely to be established through in-depth discussion, analysis, promotion, marketing and scientific research. To date, geopark has been established owing to some of the values discussed above, besides focusing more on outcrop architecture and geomorphological features, but with limited accessibility to the rock records. While the public might be aware of what is called a "rock," they may not know how amazing the rock is on the inside; hence, the question is not about its appearance on the surface but rather the material inside the rock. In this regard, the current study was carried out to evaluate the geo heritage features, for instance, waterfall landscape and rock-forming minerals. Ultimately, this study aims to educate the public by using an interactive learning platform for interpreting rock-forming minerals and their function towards sustainable geo-tourism.

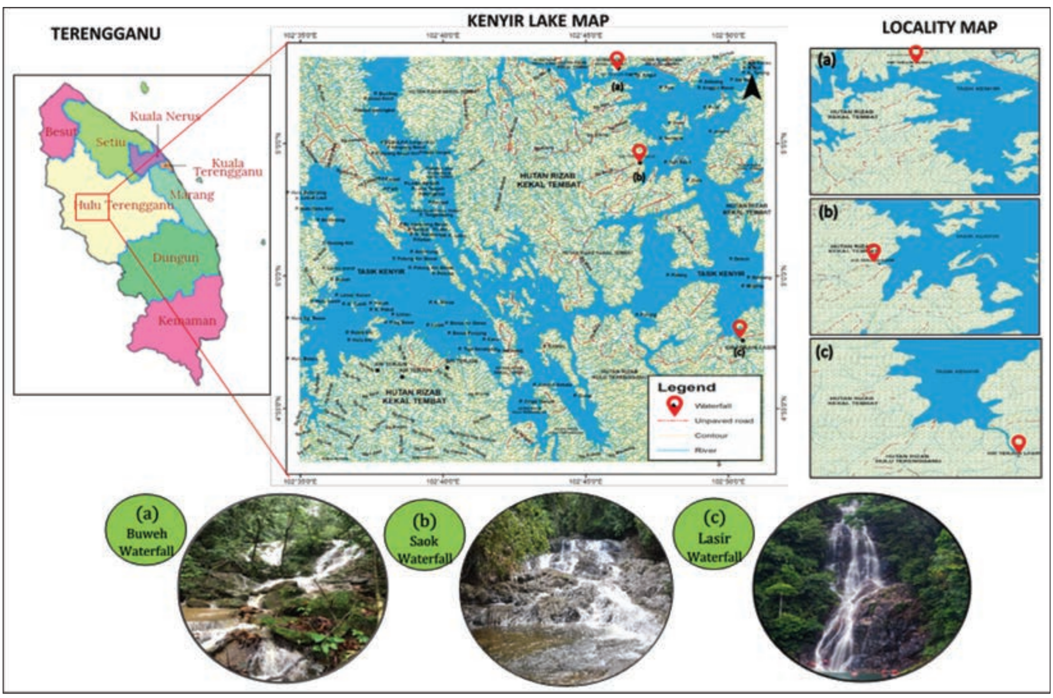


Figure 1: Showing the Kenyir Lake map in Terengganu, Malaysia, with three main waterfalls locations (i.e., photo). The photographs below the maps show the outcrop/scenery of each location within the study area

Geological setting

Kenyir Lake geology comprises sedimentary and igneous rock units that bind the whole lake area. The sedimentary rock units consist of Sungai Kerbat Shale, Sungai Petang Sandstone, Bewah Limestone, Metong Conglomerate, Gagau group (Rishworth, 1974; Sum, 2001; Sharoum *et al*., 2015; Chung *et al.,* 2017). Geology information of Kenyir Lake consists of the oldest rock (i.e., Sungai Kerbat Shale and Sungai Petang Sandstone) that was deposited in the marine environment during Late Carboniferous. A sediment consisting of gravel, silty sand and clay are believed to be transported and deposited in shallow marine environments. The carbonate rock exposed in Kenyir Lake, designated as Bewah and Taat Limestone was deposited during Late Carboniferous to Early Permian age due to the accumulation of shells and benthic organism replacing. The depositional process of carbonate rock is believed to continue until the Permian age. The Bewah and Taat Limestone (i.e., Bewah and Taat Caves) is located on the South of Kenyir Lake and near Gua Musang Formation at Kelantan and may represent a part of this rock formation. Both are the only limestone caves in Terengganu that have become a landmark and entrance gates to the National Park (Muhamad Aidil *et al*., 2017). Apart, igneous rock in Kenyir Lake is represented by volcanic rock units known as Lata Paling Andesite and a series of granitoid bodies known as Kapal Granite that has intruded into Paleozoic Sedimentary Rock (Chow, 2001). The Kapal Granite encompasses the area of Buweh, Saok and Lasir, respectively. According to Ghani et al., (2001), the eastern part of Kenyir Lake is underlain by the granitic body of Kapal batholith comprising diorite, monzogranite and largely dominated by granodiorite.

Intense tectonic activities of Peninsular Malaysia during the Late Triassic (~237 Ma) experienced a greater change in every part of the Peninsular Malaysia continent, especially the development of the orogenic belt (i.e., Western, Central and Eastern Belt). At the onset of this tectonic activity, the Sibumasu terrane drifted away from Gondwanaland and subsequently collided with Indo China/East Malaya terrane, resultantly in the formation of Bentong–Raub Suture zone (Metcalfe, 2000; Metcalfe, 2011). Kenyir Lake is located on the East Malaya Blocks, also known as the western margin of the Indochina terrane (Sukhotai back-arc). The area is underlain by sedimentary formation but prevails over plutonic and volcanic rocks (Roselee *et al*., 2018). Based on petrographic and geochemical data, the volcanic rocks at Kenyir Lake generally consist of basalt to basaltic-andesite rock types (Roselee et al., 2018). The volcanic rocks were formed during the subduction of the Paleo-tethys oceanic underneath the East Malaya Block during the Late Permian to Early Triassic age (Metcalfe, 2011; Ghani *et al.,* 2012; Habibah *et al*., 2018). Granite intrusion has metamorphosed the surrounding sedimentary rocks into metamorphic rocks (i.e hornfels and quartzite), including the Tasik Kenyir area.

The emplacement of granite during that time will form the mountainous relief in Peninsular Malaysia and lead to a prolonged weathering process and yield an amount of new sediment fill in the new basin. This new basin is terrestrial due to being predominantly comprised of the imbricated conglomerate. The terrestrial sedimentation basin is filled with sediment during the middle Jurassic to cretaceous (Rishworth, 1974; Sharoum *et al*. 2015) with less influence by the tectonic activity and sedimentation mainly controlled by fault formation. Continental sediment deposition occurs along the process of rapid denudation. The sediment composition consists of mixing sandy sediment and pyroclastic material which is the product of volcanic activities. As the denudation rate is reduced over time and complete deposition of terrestrial sediments occurs at tertiary age. It covers mostly the rock, which is quite impossible to find around Kenyir Lake nowadays. Lastly, the formation of the alluvium landscape along the river channel and riverbank around Kenyir Lake is recorded as an event of terrestrial sediment deposition during the Quaternary age (Sharoum *et al*. 2015).

Material and Methods

Petrographic Analysis

The sampling was conducted by collecting four granite rocks from Buweh, Saok and Lasir waterfalls for petrophysical analysis. As for the petrographic method, the authors used the general polished thin section to identify significant minerals, which was prepared based on King's (1957) procedure. Microscopic analysis was conducted at Universiti Malaysia Terengganu, UMT using Leica DM2500P Polarized Microscope. All the minerals within the rock samples (i.e. Quartz, feldspar, hornblende, biotite) were identified based on their optical and physical properties under the microscope. These minerals were identified according to the exact colour refracted by the optical components in minerals when stroked by light. The mineral crystal shape can also be identified from a particular mineral in the thin polished section.

Modelling

The authors selected a randomly polished thin section from any waterfall rocks due to similarities of mineral exposure for the modelling method. In this study, the modelling for the petrographic composition section, such as quartz and the various feldspar types, was constructed using integrated software *Autodesk 3Ds Max* and *Debrismaker 2.0*. Since it is important to have a technical drawing to construct a 3D mineral model with different directions, the onset of 3D modelling, a reference crystal from the *Debrismaker 2.0* software and some data from *mindat.org* was used for drawing purposes. *Debrismaker 2.0* is compatible with the 3ds software and readably functions to create a 3D model. Additionally, the software offers easy applications for modelling. For instance, the user can drag a *Debrismaker* folder into the *Autodesk 3ds* software to automatically expose any available crystal features. While the crystal features for quartz do not require the creation of polygons since the features are already created in the software, the feldspar mineral renders this necessary. The feldspar mineral can be edited using an appropriate polygon provided in the 3ds software with the selection of mesh menu. Briefly, a polygon is created by holding the Shift key from the keyboard and moving one edge and other polygons following all reference images are created using and repeated this technique.

Result and Discussions

This study has successfully evaluated the three waterfalls in Kenyir Lake: Buweh Waterfall (BW), Saok Waterfall (SW) and Lasir Waterfall (LW), which is further divided into Lasir Waterfall Left (LWL) and Lasir Waterfall Right (LWR). Two prominent geological heritage features, namely waterfall landscapes and rock units, have been evaluated and identified within those waterfalls as significant geological heritage due to their substantial aesthetic and scientific values. Most of the waterfalls exposed in Kenyir Lake encompass horsetail and fan types that are partially in contact with rocks. As a result of the constant water flow, the rocks are likely to erode faster. While BW and SW can be characterised as an early stage of waterfall development, LWR is more prone to advancing its development. With the study and discussion on petrographic or optical-mineral data for the mineral in a rock, we will, therefore, be enlightened about the exact material in a rock to understand better the landscapes and the geologic history of the area.

Geological Heritage Features and Petrographic Description

Buweh Waterfall Landscape (BW)

Buweh Waterfall (BW) is one of the best sightseeing waterfalls located outside Kenyir Lake (latitude 05°24.761′N and longitude 103°05.238′E). The Buweh waterfall (BW) is easy to access using any transportation along the paved road, with 1 kilometre from Kenyir research institute, UMT and about 5.5 kilometres from Pengkalan Gawi. Primary rainforests with numerous wood species greatly surround the area. The width of the BW is about 15 meters and the waterfall area consists predominantly of granite and granodiorite rock bodies with a maximum elevation of approximately 130 meters. Besides, the waterfall relatively steeps downstream (approximately 50° to 60°) with a different tier of falls and disappears into the ground, which enhances its uniqueness. Many medium to large rock boulders can also be seen at the lower part of the waterfall due to heavy and rapid water from the upper stream, especially during heavy rains.

Further, the horsetail type of this waterfall implies its early-stage development. In addition, using an oil painting effect will enhance the main features of the waterfall (Figure 2 (a)). This type of waterfall flows over a broad ledge – an overhanging block and partially in contact with water. Although the dangerous cascade formed naturally on the waterfall and abounding in rocks make the BW area not appropriate for any water and land activities, several facilities are provided by the Lembaga Kemajuan Terengganu Tengah (KETENGAH), such as a resting hut, public toilet and pedestrian walk.

Petrographic Features of Coarse Granite Rocks in BW

In the BW area, the mineralogy of the granite's polished thin section is equigranular, with medium to coarse-grained and major minerals comprising 41% quartz, 51% plagioclase, 11% alkali feldspar and muscovite. In contrast, the accessory minerals consist of sphene, apatite and opaque minerals (Figure 3 (a)). Additionally, muscovite and biotite occur as two different igneous classification systems, where muscovite is felsic and biotite is a mafic clot of less than 0.8 mm in length; however, both are not abundant. Besides, muscovite and biotite can be differentiated easily from their colour and pleochroism; muscovite ranges from yellow-green to dark brown, while biotite is usually brown. While quartz is anhedral with a clean surface and occurs as a late crystallised mineral, plagioclase is subhedral but rarely euhedral and often shows diffused lamellae with sharply defined albite twins. According to the ternary diagram (based on Streckeisen, 1976), the BW sample is plotted mainly on monzogranite (Figure 3 (a)).

Saok Waterfall Landscape (SW)

Saok Waterfall (SW) is another tourism destination in Kenyir Lake, located on an isolated island within the lake and coordinated at latitude 05°04.990′N and longitude 102°46.828′E with approximately 8 kilometres from Pangkalan Gawi and 15 kilometres from Buweh Waterfall. The SW has the best scenery amidst the wilderness, owing to the primary rainforest surrounding the area. Its features can be highlighted using the oil painting effect (Figure 2 (b)). Generally, this waterfall has a maximum height of 80 meters with a width of 30 meters, making it the widest among BW and LW (Figure 2 (b)). The SW area is also bounded by granite rocks, establishing the waterfall's landscape. Unlike the BW, the waterfall is not too steep and occasionally flows at certain conditions fairly; however, during rainy seasons, the water flows rather heavily, increasing erosion energy and eroding the large rocks downward. This can be seen in many waterfall areas around Kenyir Lake.

Nonetheless, compared to the BW, which takes a long canal before entering the lake body, the water in SW flows directly to the lake body, where the rock boulders emerge. According to each different water flow elevation, several falls can also be seen along the water movement. Like the BW, the SW also encompasses a horsetail type and the flowing water is partially in contact with granite rocks. However, unlike the BW, where the activities are limited, the SW offers many leisure activities such as trekking, camping and swimming, including indoor activities. Hence, this makes the SW one of the most frequently visited areas by tourists in Kenyir Lake.

Petrographic Features of Fine Granite Rocks in SW

Granitoid from the SW sample largely consist of quartz (61%), plagioclase (36%) and followed by alkali feldspar (4%), while the hornblende and biotite minerals exist as a minor portion. The plagioclase shows distinct albite twinning (Figure

3 (b)), with some looking blurry and covered by calcic groundmass. The plagioclase also can be determined through its perfect cleavage in which two directions intersect at approximately 90°. At the same time, hornblende displays a brown colour and shows two cleavages intersecting at 56° and 124° in the basal section, while quartz has a light grey to grey and is enclosed within quartzo-feldspathic groundmass. Additionally, the opaque mineral is an accessory mineral in the thin section and shows a similar appearance but is black. According to the ternary diagram (based on Streckeisen, 1976), the SW sample is plotted on the quartz-rich granitoid type.

Lasir Waterfall Landscape (LW)

Lasir Waterfall (LW), the most picturesque waterfall, is located in the southeast region of Kenyir Lake (coordinated at N04°57.919′ and E102°50.486′). Two distinct waterfalls were observed in the LW area with different landscapes, characteristics and types, namely Lasir Waterfall Left (LWL) and Lasir Waterfall Right (LWR), due to exposures on the left and right sides, respectively, when entering the Lasir area. Both were oil-painted to enhance the appearance of features. Unlike the LWR, which has a long fall canal, the LWL is only slightly steep and falls from 20 meters over granite rocks, descending into the pond below with crystal clear water about 0.5 meters in depth (Figure 2 (c)). Apart from that, the waterfalls have many beautiful upstream stages and are bounded by rock boulders and granite rocks with some quartzite. The constant water flow mostly cuts the granite rocks, eroding the surface and leaving it barren (boulders). The LWL also has a horsetail type by which the water flows partially on the rock surface.

On the contrary, the LWR is extremely steep, where the inclination surface of falls is approximately 90° with a maximum height and width of 51 and 14 meters, respectively (Figure 2 (d)). Unlike the horsetail-type LWR, the LWL encompasses more of a fan-type waterfall, which drops and slides along a steep slope whilst consistently maintaining contact with the underlying cliff. Additionally, the fall narrows upwards while the water goes down the slope under more ambient conditions but slower, widening the shape of the waterfall towards its bottom that subsequently flows down to the lake. The main attraction of the LW is that the area is equipped with an observation tower and a hanging bridge across the waterfall. Furthermore, other recreational activities are also provided in this area, such as trekking, swimming and camping.

Petrographic Features of Porphyritic Granite Rocks in LW

The thin section of granite rock consists predominantly of quartz, phenocryst plagioclase, microcline and orthoclase, while hornblende, biotite, muscovite and opaque minerals serve as accessory minerals in this rock sample. The microphotograph in figure 3 (c) shows a good albite twinning of plagioclase feldspar (especially in spot 2), while various ranges of hornblende are exposed from dull to brown-grey. Meanwhile, the hornblende mineral is obvious with two cleavages intersecting at 56˚ and 124˚ in the basal section, besides being surrounded by calcic feldspathic groundmass and is formed as a euhedral mineral. Biotite also occurs as a medium- to large-sized mineral with brown to black, while the plagioclase mineral is easily identified within the thin section due to the albite twinning with a thicker white stripe in irregular patterns. Additionally, a nice view of the microcline can be observed under the microscope with distinct plaid twinning or tartan twinning, giving a zebra-like stripe in a parallel thinnest band. Alkali feldspar usually shows simple twinning with perthite texture and occasionally tartan twinning, where sericitisation is rather common for Alkali feldspar and plagioclase feldspar. According to the ternary diagram (based on Streckeisen, 1976), LW is classified as monzogranite and syeno granite, respectively.

Granite rock outcrops and core boulders

Granite rock bodies naturally serve as a precursor of canal development for continuous waterfalls. Overall, waterfalls in the Kenyir Lake area are entirely bounded by granite rocks with a little sedimentary rock. The water source for Kenyir Lake waterfalls encompasses the barren granite rocks (i.e., exposed granite) that are generally exposed to substantial water flow from the groundwater system at a constantly high piezometric level. While the fluctuation of the groundwater system plays an important role in controlling water flow along the falls, the waterfall areas subsequently undergo an enlargement process due to repeated erosions of existing rocks by the water, which breaks down the rocks into many pieces along the joints fractured and yields an individual rock boulder. Many rock boulders can be observed in the field from several sizes (cm to m). For instance, xenolith is abundantly exposed on the granite rocks (Figure 4), indicating that the assimilation process occurs in the magma chamber with a typical mixture of sedimentary rock particles. At the early stage of collision during subduction, all rocks in the subsurface magma are melted because of extremely high pressure and temperature due to a collision. As for granite, in which the magma is cooled at a low rate in the subsurface, the material blends in a granite body and becomes xenolith. The granite rocks exposed along BW show the area of contact metamorphism in some parts. This metamorphism process is distinguished on the granite rocks according to different mineral textures, such as foliation and mineral banding.

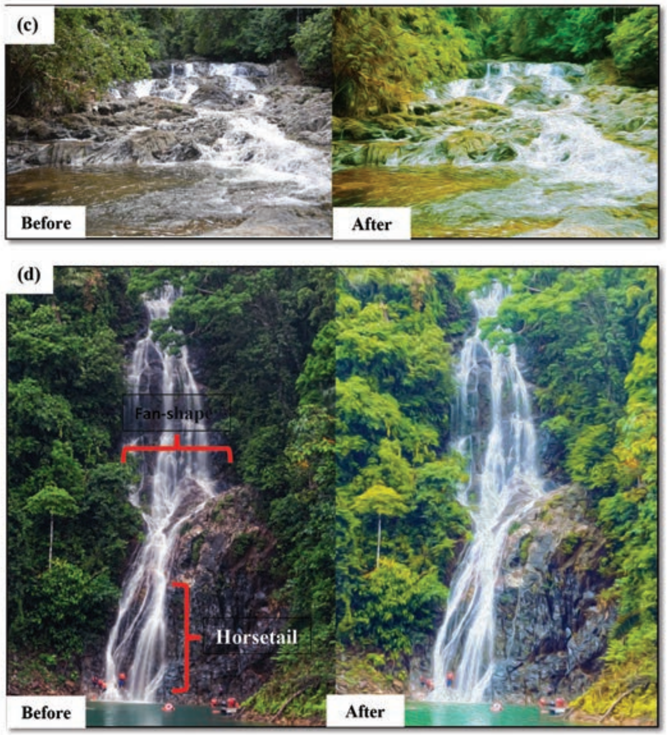
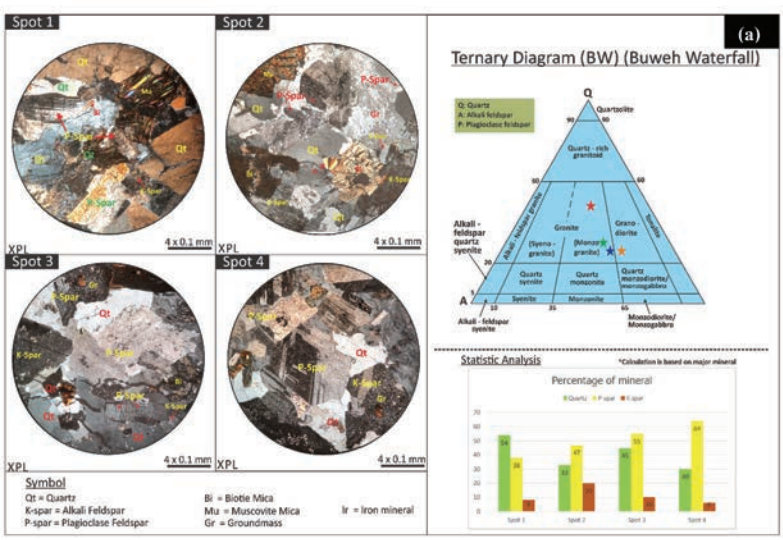


Figure 2: (a) The Oil painting effect employed to main original Buweh waterfall features to enhance the quality of the photo. The aesthetic value is captured to be more realistic from this special oil painting effect. The photo shows before and after the effect. (b) Photo showing the Saok waterfalls before and after the oil painting effect. A tiered horsetail falls clearer to observe after the effect. (c) A Lasir Waterfall Left (LWL) shows a low angle of falls with the constant flowing of water. The oil painting effect enhances a beautiful feature of this waterfall. (d) A photo of Lasir Waterfall Right (LWR), showing different appearance while using an oil painting effect. A horsetail and fan-shaped waterfall are clearer compared to the original photo



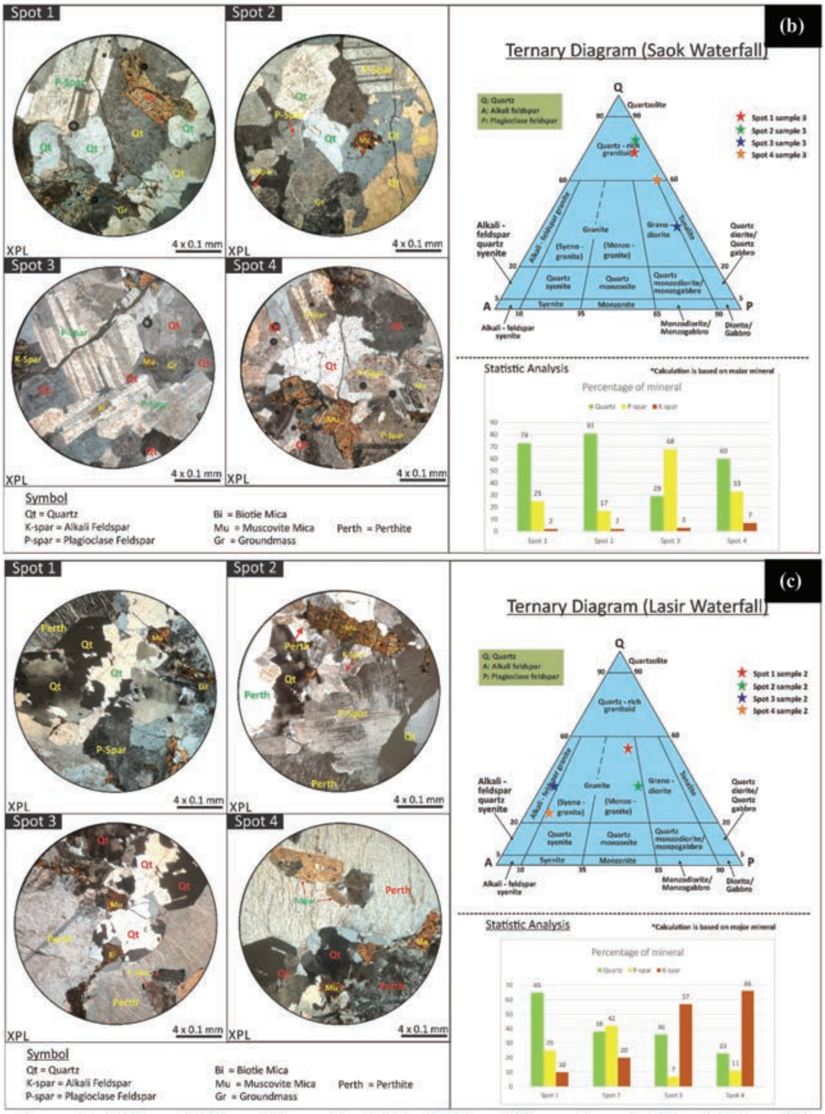


Figure 3: (a) Buweh Waterfall sample, (b) Saok Waterfall sample and (c) Lasir Waterfall sample showing a hand specimen sample (i.e., granite rock) with various types of petrographic mineral analysis (i.e., microscopic mineral). The ternary diagram is based on Streckeisen (1976)

Dolerite Dyke

Dykes are naturally formed during tectonic activities as the exceeding magma flows into a joint fractured or cracked within a pre-existing rock, then cools inside. Due to continuous plate movement, the cooling magma slowly intrudes on the surface, cutting any fractured rocks. This implies that this feature is always younger than any other rocks containing it; hence, the best deduction is that the dyke is younger than the existing rocks that are cut by this feature. In the study area, this feature is exposed in the lower part of LWL, consisting mainly of dolerite rocks that can be represented as a dolerite dyke (Figure 4). Generally, based on observation, the dolerite dyke makes a small intrusion within the

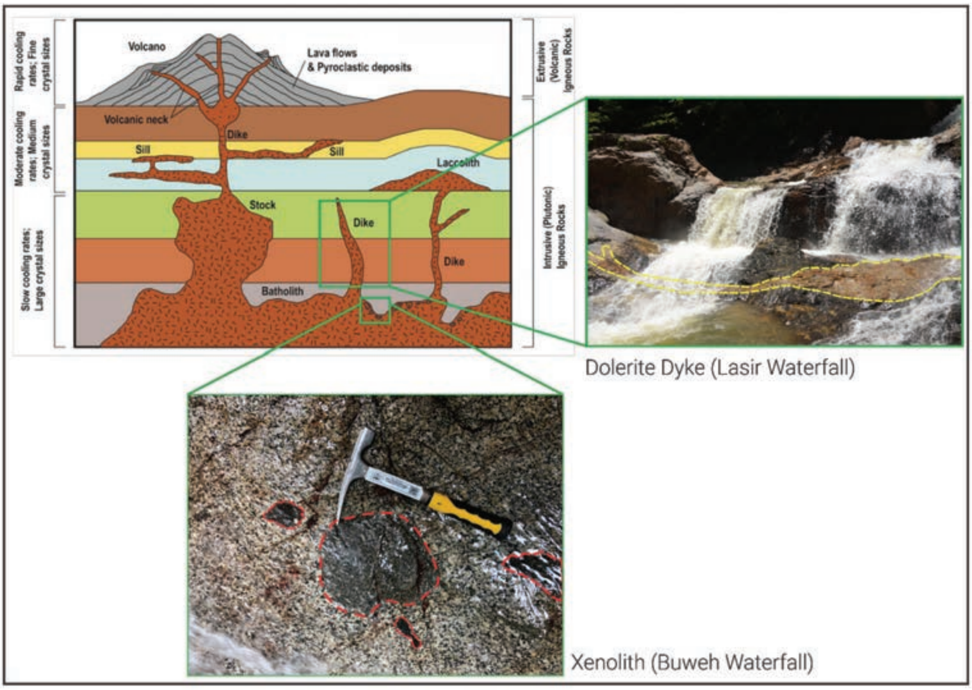


Figure 4: An exposure of dyke and xenolith features embedded on waterfall rock. The photo on the right-hand side shows the dolerite dykes intruding the granite host rock and the photo on the below side shows xenolith within the granitic rock body. A schematic magmatic model was after Bevis *et al*. (2017)

granite rock body, vertically intruded on with a limited range whereby its termination can be seen within. Therefore, it can be deduced that the granite rock is older than the dolerite dyke.

Petrographic Modelling

Quartz, a common major mineral in a granite rock with various feldspar types, have been highlighted to represent an iconic education model for educating the public about the wonderful rock-bounded waterfalls. Both quartz and feldspar are from major silicate crystal groups and have different mineral constituents, leading to different mineral lattices. Although the minerals are easy to observe with the naked eye, both can be identified and differentiated easily using a polarising microscope. However, since the public hardly knows these minerals due to the lack of information and knowledge, this modelling technique may distribute more information about rocks to the public. Specifically, the 3D modelling technique assists in the identification of the dominant features of minerals, such as the crystal system and mineral lattice. Generally, the 3D model was established using the *Autodesk 3ds Max* software. The quartz mineral was modelled using the existing crystal features in the *Debrismaker 2.0* software, while the feldspar mineral was modelled by creating editable polygons via the *Autodesk 3ds Max* software (Figure 5).

Similarly, using such a feature from the *Debrismaker 2.0* software, no polygon was created for the quartz mineral except for the feldspar mineral; however, a reference image should be inserted in the 3ds dashboard for the drawing of lines. As such, reference images were derived from the *Mindat.org* database. Different angles of the 3D mineral model were also constructed with at least two sides to display a crystal system because one side alone may not accurately display the entire silicate mineral due to its uncertain features.

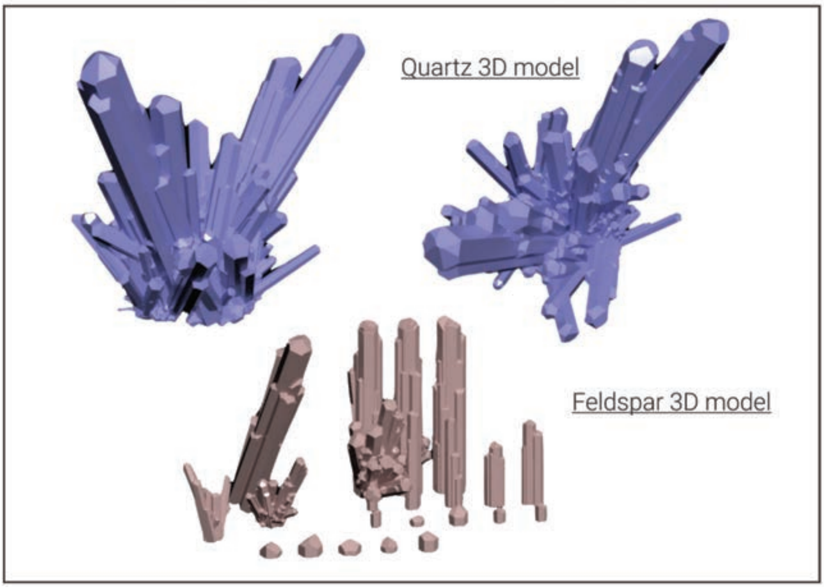


Figure 5: Showing a result of a 3D model of quartz and feldspar generated from *Debrismaker 2.0* in *Autodesk 3ds Max* software

The quartz mineral is made up of silicone tetroxide, SiO_4. The quartz 3D model can exist in many types, with common crystallographic forms (Figure 6) exposed as the trigonal crystal system. Quartz crystals may exist either as a single crystallographic form or combined with various types of forms (Rykart, 1995), based on the observation of the most common combination of crystallographic forms in quartz crystal (r+m+z), as shown in the figure. Meanwhile, the feldspar mineral comprises silicone tetroxide, SiO_4 and aluminium tetraoxide, AlO_4. In contrast with the quartz mineral, feldspar comprises various crystal systems with various feldspar minerals. Briefly, feldspar can be divided into plagioclase feldspar (e.g., albite) and potassium feldspar (e.g., microcline and sanidine) based on its dominant appearance in the thin polished section. While albite and microcline display a triclinic mineral system, sanidine, however, displays a monoclinic mineral system and such differences are due to the twining from the sharing between the lattice points of two crystals forming a symmetrical plane. Thus, many types of feldspar 3D models have been constructed using appropriate polygons based on the reference images, thereby highlighting and comparing albite, microcline and sanidine twinning. Overall, the albite and sanidine models were established as a simple contact twin (Figure 7 (a)) and polysynthetic twin (Figure 7 (b)), while the microcline mineral displays a combination between Carlsbad (Figure 7 (c)) and polysynthetic twinning.

Virtual Reality Device (VRD)

Virtual Reality Device (VRD) was proposed in the current study, which enables the public to virtually explore instant minerals (i.e., petrography) embedded in waterfall rocks, especially along Kenyir Lake, that are yet to be explored (Figure 8). This interactive tool is useful in teaching the public about minerals more easily and realistically without the need to observe via a microscope. Alternatively, the minerals are examined using this device by displaying various basic mineral features such as formula, colour, lustre, streak, hardness, specific gravity and crystal system. Since the VRD proposed in this study requires programming software to enhance its visualisation and resolution, two scopes should be highlighted from this device

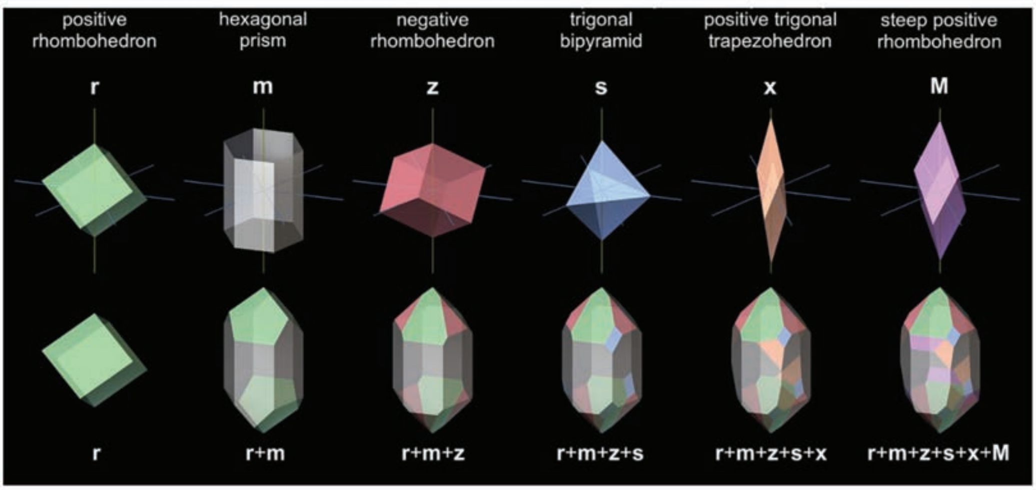


Figure 6: Variety of quartz mineral system (i.e., crystal system) derived from *mindat.org.* This illustration shows a common combination of crystallographic forms in quartz

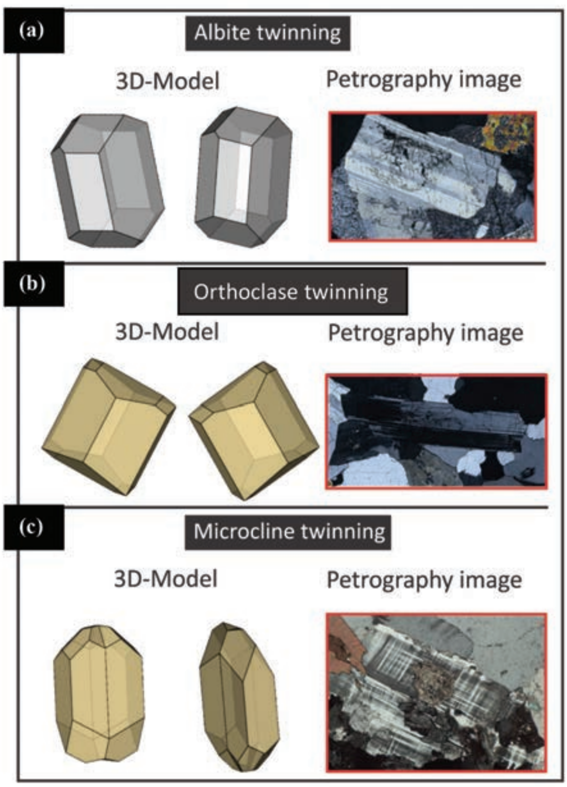


Figure 7: Showing albite, orthoclase and microcline 3D twinning crystal with polished thin section images of minerals from granite rock samples

Figure 8: Proposal of virtual reality device shortly to enhance petrographic mineral education and sustainable geotourism tools. Many aspects of mineral features equipped with the device are easier to access to increase the educational and scientific values of waterfalls rock. Virtual reality device picture was taken from the website: http:/m.shinecon.com/vr-glasses/vr- glasses-for-mobile phone.html

to increase its visibility among the public whilst supporting e-tourism: i) the VRD for educational purposes, research directory and heritage values and ii) the VRD for educational gaming and fun activities for both kids and teenagers.

Conclusion

The waterfalls in Kenyir Lake offer geo-heritage values, particularly aesthetic, educational, scientific and recreational values, all of which reveal wonderful waterfall horsetail and fan landscapes with gigantic granite outcrops and core boulders with dolerite dyke. First, as discussed in this study, the Buweh Waterfall (BW) encompasses a horsetail type with aesthetic, educational and scientific values, where the petrographic analysis for microscopic materials in the coarse granite rocks has revealed the abundance of quartz with plagioclase and potassium feldspar; however, plagioclase feldspar was more abundant than potassium feldspar. Next, the Saok Waterfall (SW) similarly encompasses a horsetail type and develops a long canal with several stages, illustrating both aesthetic and scientific values. Besides, the SW area is also surrounded by scenic rainforests, enabling the area to serve as a recreational place for tourists. As for the petrographic analysis of granite rocks in the SW, quartz was the dominant mineral, followed by potassium and plagioclase feldspar; however, the slight appearance of quartz in some spots of the thin section was because it was contrastive with mica or any fragmented mineral. While the distinct feldspar group minerals were identified as microcline and andesine-oligoclase. Lastly, the Lasir Waterfall (LW), which combines both horsetail and fan types, was recognised as the most attractive location among visitors and, hence, should develop all aesthetic, recreational, educational and scientific values.

Modelling has been done on the major minerals (quartz and feldspar) exposed from the thin polished section. Specifically, the common quartz mineral has been modelled using a combination of crystallographic forms to create a trigonal crystal system. Meanwhile, for feldspar, modelling is available for the major mineral exposed in the thin polished section with a variety of twinning in some feldspar groups, namely albite, microcline and orthoclase. Overall, the petrographic analysis and modelling of all these minerals may increase the visibility of geo-tourism in Kenyir Lake, highlighting the potential of educational and scientific geo-heritage values of waterfall rocks. Furthermore, the virtual reality device (VRD) has also been proposed as a tool to share geological information with the public; hence, this can ultimately achieve the recent sustainable development goal (SDG) 15 proposed by the Malaysian government.

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